ascent within the clouds. The writer believes that the process of hail formation as herein described, or some modification of it, is capable of completely explaining all the various phenomena of summer hail. Surely powerful air currents or winds must blow upward thru and within hail-producing clouds to sustain and buoy up the larger hailstones for the length of time necessary for them to grow to so considerable a size.

[*To be continued.*]

THE WINDS OF THE LAKE REGION.

By Prof. ALFRED J. HENRY, United States Weather Bureau. Dated December 10, 1907.

All motions of the air depend directly or indirectly upon differences in temperature. Differences in temperature arise in several ways, mostly, however, as a result of the varying amount of solar energy received at the earth's surface in the various latitudes and the unequal heating of land and water surfaces. The temperature of the equatorial regions, for reasons that need not here be stated, is high as compared with that of the polar regions; as a consequence the isobaric surfaces are inclined toward the poles, and there is, therefore, a flow of the upper air from the equatorial regions poleward in both hemispheres, with a countercurrent in the lower air from the poles toward the equator. This interchanging motion between the equatorial and the polar regions is modified by the deflecting force of the earth's rotation, by differences in barometric pressure on different parallels of latitude, and by other causes which conspire to interrupt and at times reverse the general motions here indicated.

In the Northern Hemisphere, with which we are most concerned, the principal winds are (1) the northeast trades whose polar limits do not extend much above 30° north latitude, and (2) the prevailing westerly winds of the middle latitudes. Each of these winds forms an elemental part of the general circulation of the atmosphere, and is therefore controlled and modified by general rather than local influences.

The normal temperature gradient between the equator and the poles near the surface of the earth is the principal cause of the winds. It is subject to a rather large annual inequality—that is to say, it is strongest in winter and weakest in summer—consequently the winds, particularly of the middle latitudes, also show an annual inequality both in direction and velocity; and, moreover, they are interrupted by local and temporary disturbances in temperature which produce gradients strong enough to overcome the normal gradient for the time and place. These local and temporary disturbances occur most frequently in the warm season, when the equatorial-polar gradient is weakest; hence it follows that the winds are most variable in summer and steadiest in winter. Another cause for the general seasonal changes in the force and direction of the wind is the annual migration of the heat equator. The temperature differences which arise between the continents and the oceans, as a result of such migration, cause a corresponding movement of the lower portions of the atmosphere from the colder to the warmer region.

The meteorological stations in the Lake region from which the material for the following remarks was obtained are of two classes, viz, (1) the cooperative stations at which the prevailing direction of the wind by eye observations is recorded each day, and (2) the regular stations of the Weather Bureau where the direction and force of the wind is automatically recorded thruout each of the twenty-four hours. The Weather Bureau stations, with but one exception, are stationed along the Great Lakes. Since the direction of the wind is controlled at times by temperature differences that arise between contiguous surfaces of land and water, the local winds at lake stations may not always show the general movement of the air, but merely the direction and movement of the air within a narrow zone surrounding the lake. To meet this objection use has been made of a number of cooperative stations situated at some distance from the lakes.

Winds of the cold season.—In the cold season, viz, from November to March, the winds of the Great Lakes are controlled chiefly by the meteorological conditions which prevail in the interior of the continent. The general drift of the surface winds in the United States east of the Rocky Mountains and north of about the thirty-fifth parallel of latitude for this period is from a westerly quarter; more specifically, the winds of the upper Missouri Valley, the upper Mississippi Valley, and the northern portion of the upper Lake region are northwest; in the southern part of the upper Lake region, the lower Lake region, and the Ohio Valley, west or southwest, and in the Middle Atlantic States, northwest. The mean path of the prevailing winds[1] in these regions in winter is shown in fig. 1, No. 1.

As the meridional altitude of the sun increases, the thermal conditions which prevailed over the continent in winter become reversed; the interior becomes warmer than the oceans on the same parallels of latitude on both the east and west coasts and the Gulf of Mexico on the south. The consequence is, as pointed out by Ferrel,[2] the air over the interior of the continent becomes more rare than over the oceans, rises and flows out in all directions above; while the barometric pressure is diminished, and there is an inflow below from all sides to take its place. The effect of this general warming up is not sufficiently strong, however, completely to overcome and reverse the generally eastward drift of the atmosphere in these latitudes, but it is sufficiently powerful when the pressure gradients are weak to control the direction of the winds; hence, in the transitory months of spring and early summer the winds come alternately under the influence of (1) steep temperature and pressure gradients caused by the lingering cold of the continental interior, and (2) increasing solar radiation. The effect of the latter is seen mainly during intervals of clear weather and diminishing winds, which follow the passage of an area of high pressure and cold weather. As a consequence the winds of spring are more variable than those of winter, as may be seen from fig. 1, No. 2, where are charted the prevailing winds of spring.

An interesting fact in connection with the winds of spring is the beginning of what appears to be a slight monsoon influence on Lake Michigan, viz, onshore winds from April to September of each year, due in part, it is believed, to the difference of temperature which prevails between the lake surface and contiguous land surfaces, and in part to the prevailing pressure distribution in the late spring months.

The prevailing winds on the southwest shore of the lake, as may be seen from the data for Chicago, Table 1, are northeast from April to September; on the west shore, as at Milwaukee, northeast for April and May, and southeast from June to August, or from the lake to the land in both cases. At Escanaba, on Green Bay, the prevailing winds are northerly until May, then southerly from May to October, both inclusive. The prevailing winds at Grand Haven, the only available station on the east shore, are easterly in April and southwesterly from May to September, with, however, a large percentage of northwesterly winds in July and August. Thus it will be seen

[1] The term "prevailing" unfortunately does not afford any indication of the relative frequency of the winds so designated. If the wind blew an equal number of times from each of the eight principal points of the compass, it would be said to have no prevailing direction, there being 12.5 per cent from each direction. If, on the other hand, it had blown as much as 13 per cent from any direction, that direction would be designated as the prevailing one. The term "prevailing" may, therefore, indicate winds of frequency ranging between 13 and 100 per cent. In Table 1 is given the percentage of wind from each of the eight principal points of the compass as determined hourly by automatically recording instruments.

[2] See "A Popular Treatise on the Winds".

that for the summer months, as graphically shown in fig. 1, No. 3, the winds are generally onshore. These onshore winds form about 20 per cent of the total winds observed. They prevail at times when the pressure gradients are weak, and subside as soon as stronger gradients appear. This exception should be noted. A pressure gradient that will produce a land wind on the west shore of the lake produces a lake wind on the east shore. The former are produced chiefly by the slow eastward drift of areas of high pressure across the Lake region in which the seat of greatest cold and highest pressure is found

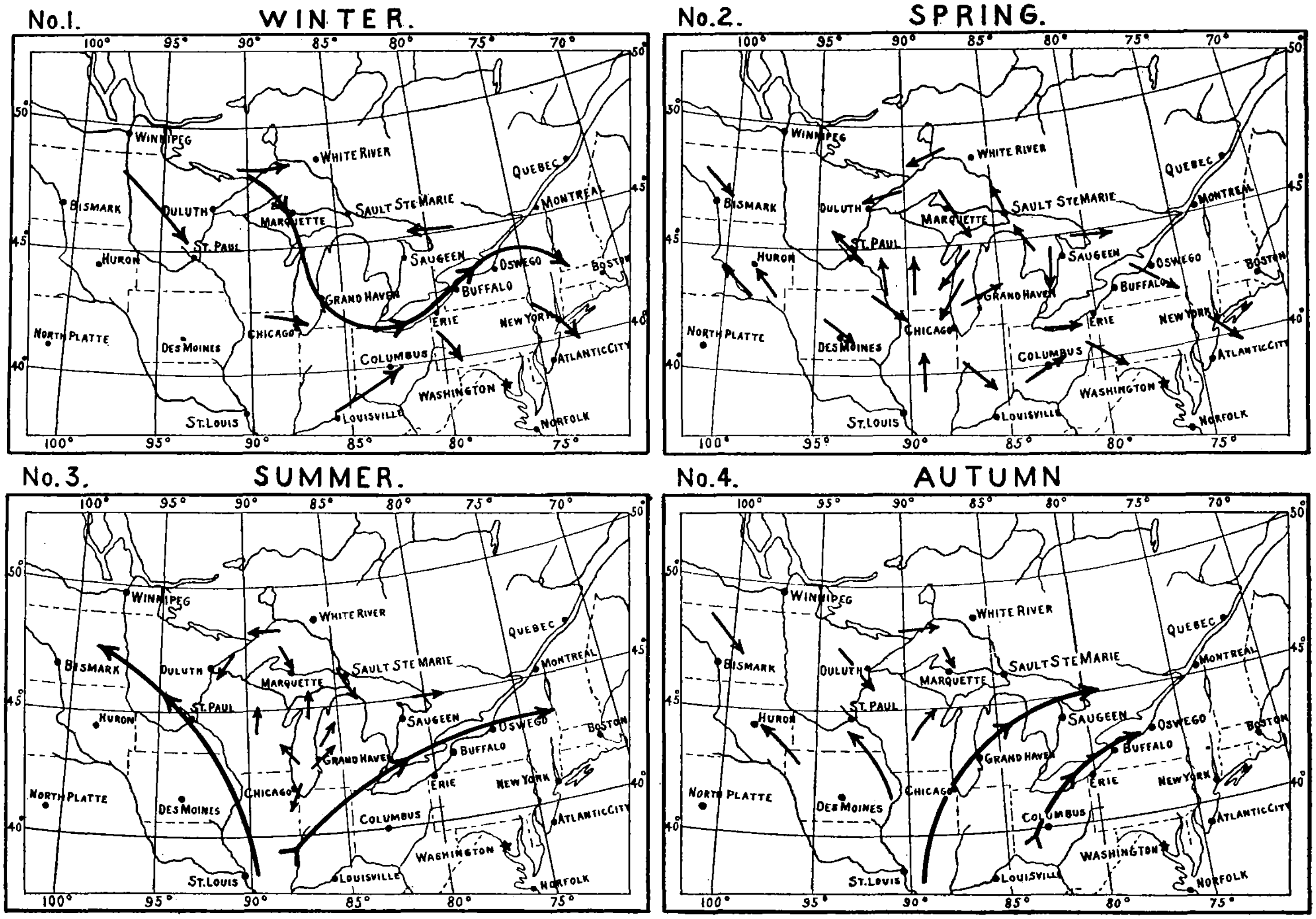

FIG. 1.—Prevailing winds of the Lake region at different seasons.

to the northward of the Lake region. The movement of the northern portion of the respective highs is a trifle faster than that of the southern portion, and the longer axis of the high therefore assumes a north-northeast to south-southwest direction, which, it may be recalled, produces a steady northeast wind over the Lake region, and this wind will continue day and night so long as the pressure distribution is favorable. The lake wind, on the other hand, is the result of diurnal changes in temperature coupled with favorable pressure distribution, as will be explained in the following paragraphs.

In Table 3 is given the average difference between the surface air and water temperatures at several stations along the Great Lakes. The period of observation was about five years in length, and the temperatures of both air and water were observed at the same moment of time.

These data show that the greatest differences between air and water temperatures are found along Lake Superior, where they amount to about 10° on the average for the months of May to July, inclusive, diminishing to about half that amount in August, and to zero in October. In November the water temperatures along the shore are about 6° warmer than the corresponding air temperatures.

On the west shore of Lake Michigan the difference between land and lake temperatures is greatest in June and July, when it amounts to about 8° at Chicago, over 10° at Milwaukee, and about 6° at the Straits of Mackinaw. The difference diminishes steadily until October, when the water is warmer than the air at the Straits of Mackinaw, but still colder than the air over the southern and central portions of the lake. In November the surface waters at Milwaukee are warmer than the air, while at Chicago they are nearly equal.

At Grand Haven, on the east shore, the surface waters from May to October appear to be a little warmer than the air; The observations were made, however, in the river rather than along the lake shore, and they may not accurately represent the temperature of the lake waters; nevertheless there does not appear to be any doubt as to the main fact shown by these observations, viz, that the water along the eastern shore is warmer than it is along the western shore.

The observations for Lake Huron were made at Alpena, a station on Thunder Bay. The differences here are uniformly small, perhaps due to poor circulation of water between the bay and the lake.

On Lake Erie there is a difference of about 5° during April, May, and June between the temperature of the air and the water along the shore, judging from the observations at Cleveland. For July, August, and September the air and lake temperatures are nearly the same, but in October

TABLE 1.—*Percentage of frequency of wind from the eight principal points of the compass (by the hourly records of self registers.)*

Stations and directions.		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
		%	%	%	%	%	%	%	%	%	%	%	%	%
Duluth, Minn.† (5 years, 1891–1895.)	N	10	9	8	8	10	7	11	11	10	12	10	11	10
	NE	8	14	25	44	38	28	21	20	20	19	10	6	21
	E	6	6	14	18	17	23	14	19	13	9	5	4	12
	SE	4	2	4	4	2	2	3	2	2	3	9	4	3
	S	5	3	3	1	2	3	3	3	2	2	6	5	3
	SW	17	19	14	4	7	6	10	13	19	12	20	23	14
	W	16	16	9	4	9	11	12	9	11	15	16	21	12
	NW	31	25	18	13	11	14	21	18	21	24	22	23	20
	Calm	3	6	4	4	6	5	5	4	2	3	2	2	4
Marquette, Mich (10 years, 1894–1903.)	N	6	9	15	18	17	16	13	15	9	9	8	6	12
	NE	2	6	11	13	11	9	11	12	8	8	6	4	8
	E	2	4	4	5	5	7	6	6	4	3	2	2	4
	SE	8	6	9	10	10	11	9	9	10	12	8	6	9
	S	16	9	12	10	10	10	10	10	16	17	16	15	13
	SW	14	12	10	7	10	11	15	14	20	15	16	17	13
	W	23	22	11	8	7	8	11	12	13	13	21	26	15
	NW	29	31	26	27	29	25	24	20	21	21	24	25	25
	Calm	0	1	0	1	1	2	2	1	0	0	0	0	1
Port Arthur, Ont (10 years, 1894–1903.)	N	5	5	10	11	13	8	8	8	8	6	9	4	8
	NE	6	7	17	21	23	20	19	17	11	13	6	5	14
	E	2	5	9	11	10	14	9	7	11	9	5	2	7
	SE	2	4	6	10	9	8	8	10	9	6	4	3	7
	S	3	3	3	1	3	4	4	3	5	5	4	3	3
	SW	11	11	9	4	4	5	7	8	10	7	12	14	8
	W	32	27	14	10	8	9	12	14	15	18	30	32	18
	NW	25	24	21	21	18	16	17	19	19	23	21	25	21
	Calm	15	13	11	12	13	16	15	14	12	13	9	12	14
Parry Sound, Ont (10 years, 1894–1903.)	N	14	14	12	14	10	9	9	12	11	11	14	17	12
	NE	6	6	7	9	7	6	6	6	9	7	5	6	7
	E	21	16	16	14	15	11	13	13	11	18	18	23	16
	SE	12	8	10	8	7	5	6	7	12	13	12	11	9
	S	7	8	9	7	10	8	9	7	9	8	9	4	8
	SW	9	8	9	8	11	14	16	13	16	11	12	9	11
	W	17	24	23	22	24	30	27	29	20	19	18	17	22
	NW	9	11	9	11	8	8	7	6	9	11	11	9	9
	Calm	5	6	5	6	8	9	7	6	4	3	2	3	5
Milwaukee, Wis.† (5 years, 1891–1895.)	N	7	8	12	10	10	8	10	13	10	9	9	9	10
	NE	5	7	13	21	19	16	13	12	9	7	5	6	11
	E	2	3	6	14	12	12	12	9	7	3	3	2	7
	SE	9	10	13	18	18	20	20	20	17	15	7	6	14
	S	8	8	7	6	6	8	6	9	15	10	16	11	9
	SW	15	16	16	10	15	12	17	17	19	19	15	21	16
	W	26	26	14	8	11	12	11	9	10	15	20	22	15
	NW	28	24	18	13	10	9	8	11	14	20	23	23	17
	Calm	0	0	0	1	0	1	2	1	0	0	0	0	0
Chicago, Ill (10 years, 1894–1903.)	N	7	9	12	14	11	9	8	8	9	10	9	8	9
	NE	7	9	16	25	24	25	23	24	15	13	10	7	17
	E	5	5	8	9	7	10	10	12	8	7	3	3	7
	SE	7	6	10	11	11	11	13	10	10	10	5	4	9
	S	15	11	14	15	16	13	11	12	21	19	20	15	15
	SW	17	13	14	10	16	15	18	17	17	16	17	21	16
	W	23	26	14	9	11	10	13	9	12	15	17	23	15
	NW	17	20	14	7	5	6	6	6	8	10	17	18	11
	Calm	0	0	0	0	0	0	0	0	0	0	0	0	0
Grand Haven, Mich.† (5 years, 1891–1895.)	N	10	12	10	9	7	6	8	11	8	15	8	8	9
	NE	8	10	13	9	7	4	10	8	8	7	10	10	9
	E	15	9	11	20	9	10	7	9	8	10	9	11	11
	SE	16	9	14	16	15	12	7	10	16	17	16	16	14
	S	4	6	10	6	9	7	6	6	9	4	6	6	7
	SW	15	19	15	16	29	24	24	23	27	16	19	24	21
	W	9	10	11	7	11	19	13	9	6	11	8	10	10
	NW	23	19	16	17	14	18	23	21	16	20	20	15	18
	Calm	0	1	0	0	0	0	1	2	0	0	0	0	0
Alpena, Mich.† (5 years, 1891–1895.)	N	6	7	12	12	13	9	7	11	5	6	5	5	8
	NE	4	4	5	7	8	9	5	7	4	4	5	5	5
	E	5	7	7	17	16	10	7	8	7	5	4	6	8
	SE	8	9	14	21	24	29	25	20	21	17	8	6	17
	S	11	9	7	8	6	6	9	8	12	11	16	12	9
	SW	12	11	10	4	7	8	10	11	16	18	20	24	13
	W	34	25	18	11	11	12	13	12	17	16	21	26	18
	NW	17	23	25	21	15	17	26	22	18	23	21	16	20
	Calm	3	2	2	1	1	0	0	1	1	0	0	0	1
Detroit, Mich (10 years, 1894–1903.)	N	7	8	7	12	9	9	10	11	10	10	8	7	9
	NE	9	12	19	20	17	16	14	18	12	13	7	7	14
	E	6	5	10	12	12	12	9	11	7	8	3	3	8
	SE	5	4	7	7	8	6	6	7	8	8	6	4	6
	S	9	5	7	6	8	9	8	7	10	10	11	8	8
	SW	29	27	21	17	24	23	26	24	28	25	30	36	26
	W	24	25	17	13	13	16	16	12	15	16	22	22	17
	NW	12	15	11	11	8	9	11	10	10	11	13	11	11
	Calm	0	0	0	0	0	0	0	0	0	0	0	0	0
Buffalo, N. Y (10 years, 1894–1903.)	N	5	5	7	8	6	6	7	8	9	8	8	4	7
	NE	5	7	10	12	11	8	8	9	9	9	6	7	8
	E	10	8	12	13	12	8	7	10	8	11	8	9	10
	SE	6	4	5	5	5	4	4	4	5	7	6	5	5
	S	10	9	11	9	8	9	9	10	15	13	12	11	10
	SW	20	23	21	24	29	31	30	25	24	21	20	22	24
	W	30	32	24	19	23	26	26	22	21	19	26	29	25
	NW	14	12	10	9	7	7	8	10	9	13	15	12	10
	Calm	0	0	0	0	0	0	1	2	6	0	0	0	0

† Unfortunately the detailed records from self-registers at these stations were not tabulated after 1895.

TABLE 2.—*Percentage of westerly and easterly winds in the Lake region.*
(From Table 1.)

Station and direction.	Winter.	Spring.	Summer.	Autumn.	Year.
St. Paul, Minn.:	%	%	%	%	%
Westerly	57	40	42	44	46
Easterly	26	39	34	32	33
Duluth, Minn.:					
Westerly	64	30	38	53	46
Easterly	18	55	44	30	37
Marquette, Mich.:					
Westerly	66	45	47	55	53
Easterly	13	26	27	20	21
Milwaukee, Wis.:					
Westerly	67	38	35	52	48
Easterly	17	45	45	24	33
Chicago, Ill.:					
Westerly	59	33	33	43	42
Easterly	18	40	46	27	33
Grand Haven, Mich.:					
Westerly	48	45	58	48	50
Easterly	35	38	26	34	33
Alpena, Mich.:					
Westerly	63	41	44	57	51
Easterly	18	40	40	25	31
Detroit, Mich.:					
Westerly	67	45	49	56	54
Easterly	18	38	33	24	28
Buffalo, N. Y.:					
Westerly	65	55	62	56	59
Easterly	20	28	21	23	23

TABLE 3.—*Differences between air and water temperature in the Lake region.*
(Averages of about five years.)
("+" = air warmer than water; "—" = water warmer than air.)

Station.	March.	April.	May.	June.	July.	August.	September.	October.	November.
	°	°	°	°	°	°	°	°	°
Lake Superior:									
Duluth	....	....	+12.8	+ 8.4	+ 9.7	+4.2	+3.1	+0.4	—7.2
Marquette	....	....	+ 9.2	+12.2	+10.5	+6.4	+6.6	+1.3	—5.1
Lake Michigan:									
Milwaukee	....	....	+ 6.4	+ 9.3	+12.3	+6.5	+6.9	+1.8	—2.1
Chicago	....	+3.9	+ 3.5	+ 7.5	+ 8.4	+3.8	+4.7	+2.2	+0.4
Grand Haven	+1.8	+1.4	— 2.5	— 2.7	— 2.8	—2.6	—0.4	—0.1	+0.9
Lake Huron:									
Alpena	....	....	+ 0.7	+ 1.4	+ 1.7	+1.2	+2.2	+2.0	....
Lake Erie:									
Cleveland	....	+6.1	+ 5.0	+ 4.9	+ 0.9	+0.8	+1.8	—0.4	—2.4
Buffalo	....	+3.7	+ 4.9	+ 3.2	— 0.2	—0.2	+0.6	—1.8	—1.6

and November the lake water is somewhat warmer than the air. Observations made at Sandusky and Toledo both show less variation than at Cleveland, but, as at Alpena, the difference may be ascribed to local causes.

All water temperatures here mentioned refer to the temperature as determined along the shore, generally in shallow water. The temperature of the surface water in mid-lake is known to be considerably lower, especially on Lake Superior.

Since the surface layers of air over the Great Lakes take their temperature largely from that of the water with which they are immediately in contact, there must be a comparatively shallow body of relatively cold air overlying each of the larger lakes, corresponding to the area of low water temperature in mid-lake. The central portion of this mass of cooler air, in the absence of strong pressure gradients, must be a region of calms or light airs, while the air near shore, being subject to the control exercised by the diurnal contrasts in temperature over the land, the latter being greater than over the lake, must tend to move from the lake toward the land in response to the gradient. The winds thus created are known as lake winds. They arise mostly in the forenoon hours of tranquil summer days and continue for a few hours after sunset, when they shift to a land quarter.

The lake winds thus described are confined mostly to the west shore of Lake Michigan, where it may be remembered the prevailing wind at land stations is in a contrary direction, viz, from southwest to south.

The temperature gradients that will produce an easterly wind on the western shore of Lake Michigan, on the hypothesis of a region of relatively cool air in mid-lake, will produce a westerly wind along the east shore of the lake, and this local and temporary influence, uniting with the forces which maintain the general circulation of the atmosphere in the latitudes of the Lake region, will cause an excess of westerly winds along the eastern shore as compared with the western shore. (Compare the summer winds at Milwaukee and Grand Haven, Table 2. See also the record for Parry Sound.)

The winds of summer.—In summer the prevailing winds of the Lake region are southwest to south, except on Lake Superior, where the direction seems to be controlled by local causes. The northeast winds of spring along the northwest shore of that lake from Duluth to Port Arthur continue well into the summer. The winds along the south shore are generally northwest.

The southerly winds of the lower Mississippi Valley apparently divide into two branches in late spring, one branch forming the southeast winds of summer in the Missouri Valley and the Plains, the other the southwest winds of the Ohio Valley and the lower Lakes.

The temperature of the surface waters of the Great Lakes reaches a maximum on lakes Erie and Ontario in July; on the larger lakes, Michigan, Huron, and Superior, the maximum is deferred until August. The closest agreement between air and water temperatures occurs in October.

The winds of autumn.—The autumn, as a whole, is a season of diminished temperature contrasts between land and lake surfaces, respectively, and accordingly we find that the lakes exert the minimum effect upon the direction of the winds at this season of the year. In autumn southerly winds reach their farthest northing, extending well into the Lake Superior region and the Province of Ontario to the northward. In November there is a sharp change in the direction of the wind in northern Wisconsin and the upper portion of the Lower Michigan Peninsula. In this territory northwesterly winds gain the ascendancy and maintain it thruout the winter. In the southern portion of the Lake region the winds in November become westerly and hold that direction until the succeeding spring.

One other point remains to be mentioned, viz, the probable effect of the contour of the several lake basins on the direction of the wind. The tendency of the surface winds to follow the course of a valley is well known. The lower Lakes, together with their connecting rivers, form a great shallow depression, which, on account of the diminished friction afforded by the water surfaces, must provide an easy path for the winds—a path, moreover, which it seems probable all winds between west and north follow unless compelled by strong pressure and temperature gradients to cross the lakes obliquely.

The average hourly velocity.—The average hourly velocity of the wind in the Lake region on the mean of the year is about 10 miles an hour. The wind velocity during the twenty-four hours is not constant, but increases from a minimum in the early morning to a maximum in the afternoon at about the same time that the maximum temperature occurs; indeed the resemblance between the curves showing the daily march of the temperature and the daily increase in the wind velocity is quite marked.

The wind in autumn and winter is above the daily average about eight hours out of the twenty-four and below the remainder of the time. In spring and summer it is above the daily average about ten hours out of the twenty-four and below the remaining fourteen hours.

The periodic diurnal range of the velocity of the wind is least in winter and greatest in spring and summer; thus the average range at six stations for January is 2 miles; for April 4.5 miles; for July 4.6 miles; and for October 3.4 miles. Another way of expressing this fact is to say that the winds of winter are steadier than those of spring and summer in the sense that the day and night winds are nearly equal in force. In the summer the winds of the nighttime fall as much as 4 or 5 miles an hour, on the average, below those of the afternoon.

The diurnal period of the winds at Marquette and Cleveland differs from that of other stations in that the daily minimum falls in the early evening hours instead of the early morning hours. At Marquette the minimum wind force of the day is experienced at about 5 p. m. in January; 9 p. m. in April; 8 p. m. in July; and 6 p. m. in October. At Cleveland the minimum occurs at 6 p. m. in January; at 7 p. m. in April; at 8 p. m. in July; and at 6 p. m. in October. The Marquette station also shows a prominent increase from the evening minimum to the secondary maximum in the early morning hours, a feature not generally observed elsewhere. The early minimum at Marquette is well marked, the average difference between it and the morning secondary minimum in July being about 3 miles. Its cause is not clearly understood.

The wind velocities given in Table 4 are subject to a correction for the varying altitude of the anemometers above the surface of the ground. In general, the greater the height the greater the velocity, other things being equal, but thus far no satisfactory correction for altitude has been determined.

TABLE 4.—*Average hourly wind velocity in the Lake region, in miles and tenths per hour.*

(For the period 1891-95.)

Station.	January.			April.			July.			October.			Year.		
	Highest.	Lowest.	Mean.	Highest.	Lowest.	Mean.	Highest.	Lowest.	Mean.	Highest.	Lowest.	Mean.	Highest.	Lowest.	Mean.
St. Paul, Minn	8.7	6.1	7.4	11.5	7.1	8.9	9.3	4.4	6.5	10.4	6.4	7.9	9.9	6.1	7.6
Marquette, Mich	10.7	8.8	10.0	12.6	7.5	9 7	10.5	5.3	8.6	13.5	10.4	11.7	11.8	8.6	10.2
Chicago, Ill	18.9	16.3	17.7	20.9	17.6	18.9	15.5	12.3	14.0	18.9	16.4	17.4	18.6	16.5	17.3
Detroit, Mich	13.1	10.4	11.3	14.5	9.8	11.7	12.2	6.9	8.9	13.8	9.9	11.3	13.4	9.4	10.9
Cleveland, Ohio	13.1	11.6	12.3	13.9	9.7	11.3	11.8	7.7	9.5	14.3	11.2	13.0	13.7	10.4	11.9
Buffalo, N. Y	14.8	12.9	13.8	13.1	8.8	10.5	12.7	6.9	9.4	13.9	10.7	12.1	13.4	10.2	11.4

The significance of the figures of wind velocities, given in Table 4, is as follows: In the column headed "highest" the figures represent the average for that one of the afternoon hours which gives the highest value; and, conversely, the figures under the column headed "lowest" express the average for that one of the night hours which gives the lowest value. The values under the column headed "mean" are the arithmetical means of all of the hourly readings in the month, 744 in the case of a 31-day month, etc.

The elevations of the anemometers above the ground during the period of observations, 1891-95, were as follows:

Station.	Height above ground Jan. 1, 1891.	Subsequent changes.
	Feet.	
Buffalo, N. Y	108	Increased to 123 feet October 7, 1895.
Chicago, Ill	272	Increased to 274 feet October 15, 1892.
Cleveland, Ohio	103	Increased to 130 feet April 3, 1892.
Detroit, Mich	158	Increased to 161 feet July 31, 1891.
Marquette, Mich	95	No change.
St. Paul, Minn	124	No change.

The wind movement is greatest on the average in spring and autumn, altho high single velocities, or squall winds, may occur in any month of the year. Table 5 contains a list of high wind velocities recorded in the Lake region within the season of navigation during the last thirty-six years.

High winds in the Lake region.—A cursory examination of Table 5 brings out the important fact that the storm winds of the Great Lakes, for a single season, are largely sporadic, and in general not confined to any particular quarter, altho, as a rule, westerly winds predominate. The storms which produce high winds in the Lake region may be divided into three main groups. In the first group may be included all storms whose centers move eastward north of Lake Superior; in the second may be included storms which approach the Lake region from the south or southwest, or whose centers approach from the west, but south of Lake Superior; and, finally, in the last group

TABLE 5.—*Maximum wind velocities (in miles per hour) in the Lake region during season of navigation.*

Station and period of record.	April.				May.				June.				July.			
	Velocity.	Direction.	Year.	Date.	Velocity.	Direction.	Year.	Date.	Velocity.	Direction.	Year.	Date.	Velocity.	Direction.	Year.	Date.
Lake Superior.																
Duluth (1871–06)....	60	nw.	1877	20	60	ne.	1877	20	63	ne.	1904	3	48	nw.	1897*	2
Marquette (1871–06)	49	w.	1891	30	52	se.	1896*	25	45	se.	1899	13	68	sw.	1901	20
S.Ste.Marie (1888–06)	60	se.	1893	20	50	se.	1892	18	45	nw.	1898	1	42	nw.	1898	28
Lake Michigan.																
Milwaukee (1871–06)	54	sw.	1878	10	49	se.	1896	25	60	sw.	1880	4	60	sw.	1874	24
Chicago (1871–06)...	72	ne.	1893	20	62	e.	1894	18	72	nw.	1892	13	72	w.	1897	5
Escanaba (1871–06).	48	n.	1878*	10	40	w.	1906	31	40	s.	1876	18	37	nw.	1901	20
Lake Huron.																
Alpena (1873–06) ...	49	nw.	1893	4	44	nw.	1905	9	48	w.	1881	13	60	sw.	1875	15
Port Huron (1874–06)	60	sw.	1893	13	54	sw.	1896	17	52	w.	1898	12	56	n.	1879	11
Detroit River.																
Detroit (1871–06) ...	72	ne.	1893	20	74	sw.	1893	23	60	nw.	1890	17	54	n.	1893	7
Lake Erie.																
Toledo (1871–06)....	60	w.	1892	5	52	e.	1882	6	50	w.	1888	13	49	nw.	1892	24
Sandusky (1877–06).	52	nw.	1880	19	46	nw.	1878	10	57	nw.	1882	29	69	n.	1879	11
Cleveland (1871–06).	60	n.	1901	20	60	nw.	1905*	11	60	nw.	1898	12	66	w.	1896	26
Erie (1873–06)......	60	se.	1894	10	60	s.	1875	....	40	w.	1899	7	56	w.	1876	....
Buffalo (1871–06) ...	57	sw.	1897	20	58	sw.	1884	2	56	sw.	1893	11	60	sw.	1876	5
Lake Ontario.																
Oswego (1871–06)...	54	se.	1893	20	40	se.	1894	20	36	ne.	1885	5	38	n.	1888	11

Station and period of record.	August.				September.				October.				November.			
	Velocity.	Direction.	Year.	Date.	Velocity.	Direction.	Year.	Date.	Velocity.	Direction.	Year.	Date.	Velocity.	Direction.	Year.	Date.
Lake Superior.																
Duluth (1871–06)....	51	nw.	1904	19	78	ne.	1881	16	55	ne.	1896	30	70	nw.	1905	24
Marquette (1871–06)	48	sw.	1890	2	61	s.	1893	21	48	sw.	1905	7	48	sw.	1894	14
S.Ste.Marie (1888–06)	50	nw.	1897*	29	56	nw.	1904	30	50	nw.	1893	14	52	nw.	1896	18
Lake Michigan.																
Milwaukee (1871–06)	52	w.	1896	9	48	w.	1890	20	60	sw.	1880	16	55	se.	1906	16
Chicago (1871–06)...	72	sw.	1898	16	72	sw.	1900	11	63	se.	1898	19	76	s.	1898	7
Escanaba (1871–06).	44	n.	1875	20	46	w.	1906	11	45	sw.	1880	16	60	n.	1877	8
Lake Huron.																
Alpena (1873–06) ...	41	nw.	1901	29	48	w.	1884	10	52	e.	1905	20	50	sw.	1874	5
Port Huron (1874–06)	52	n.	1896	8	46	sw.	1900*	11	54	sw.	1887	24	58	sw.	1894	26
Detroit River.																
Detroit (1871–06) ...	40	sw.	1904	20	43	sw.	1900	11	61	nw.	1891	31	76	sw.	1895	26
Lake Erie.																
Toledo (1871–06)....	45	ne.	1875	1	60	s.	1898	24	60	w.	1906	27	68	sw.	1906	21
Sandusky (1877–06).	63	ne.	1885	9	52	nw.	1897	16	54	n.	1885	29	62	nw.	1879	20
Cleveland (1871–06).	58	nw.	1896	10	66	nw.	1897	16	62	nw.	1894	11	73	s.	1895	26
Erie (1873–06)......	40	w.	1895	28	45	sw.	1895	12	48	w.	1887	24	54	w.	1891	23
Buffalo (1871–06) ...	58	sw.	1904	20	78	w.	1900	12	75	sw.	1906	28	80	w.	1900	21
Lake Ontario.																
Oswego (1871–06)...	51	n.	1893	29	51	nw.	1892	26	56	se.	1893	14	48	w.	1900*	21

* Also other years.

may be included storms which occasionally move northward along the Atlantic coast, increasing in energy as they reach higher latitudes, and frequently curving inland over the eastern portion of the Middle Atlantic States, as on November 13, 1904.

The storms of the first group are by far the most numerous and the least dangerous. The storms of the second group are not so numerous as those of the first, but they are generally attended by dangerous winds, at least over some portion of the Lake region. Storms of the third group rarely affect the upper lakes, but they cause dangerous winds over lakes Erie and Ontario.

Rarely does it happen that a storm, no matter to which of the above-mentioned groups it may belong, is equally severe in all portions of the Lake region. In the summer season, however, thunderstorms may prevail over the entire Lake region on the same day.

INFLUENCE OF VEGETATION IN CAUSING RAIN.

The following correspondence is published as a matter of interest to many readers:

Allow me to ask your valued opinion on the following matter: Admitting two clouds equally saturated with humidity to hang above two soils, the one teeming with luxuriant vegetation, the other barren and naked, parched by the sun, exuding heat, is the probability greater or not of the cloud in the first instance discharging itself in rain? Or, in other words, do the trees and the greater humidity of the one soil exercise no influence whatever in attracting rain?

* * * You assume two clouds hanging above two different regions, in one of which the soil has a luxuriant vegetation, while the other is barren, naked, and hot; and you ask whether the soil or the vegetation has any influence in "attracting rain".

If the clouds were low down, close to the soil, the warm, hot soil would doubtless contribute a little heat to evaporate the cloud particles and prevent rain, and by thus giving the cloud greater buoyancy the latter might rise a little higher. But neither the wet soil nor the dry soil would be likely to cause any rain.

If you have in mind the ordinary cumulus cloud, which is several thousand feet above the ground, then dry soils and moist soils would have no influence whatever upon the clouds, unless the areas of these dry and wet regions were extensive, such as a hundred miles square, in which case the great mass of warm, dry air would prevent the formation of rain, while on the other hand the mass of warm, moist air would not prevent rain, but would be helpful in case other circumstances conspired.

Neither dry land nor vegetation has any power whatever to "attract rain" from the clouds. If the raindrops are in the clouds they will fall toward the ground by the attraction of gravitation—not by any special attractive power of trees or soils. They will undoubtedly begin to fall in the clouds as soon as they are formed, and the fundamental question is, "How can we make the cloud particles join together into raindrops?" and not, "How can we attract the drops out of the cloud?" So far as meteorologists know at the present time the only place in which raindrops are formed in the warm climates of the globe, or warm seasons of the year, is in the midst of a rapid, ascending current of air. And if you notice that rain falls over a wet soil, rather than over a dry one, you will undoubtedly find that there are ascending currents of air over the wet soil, and descending currents over the dry soil. A descending current warms the air and prevents the formation of raindrops just as truly as an ascending current cools the air and favors the formation.

It is not worth while to appeal to electrical attraction or any other principle in physics, except the cooling by ascent and the mixing of air currents in cloudy regions where temperatures are but little above freezing.

Altho we do not know the exact details of the method of forming raindrops, as distinguished from fine cloud particles, yet it is safe to say that ascending and mixing are the important items, and that when once formed the drops will fall toward the ground. On their way down thru a stratum of very hot, dry air they may evaporate, so that the observer sees the streaks of falling rain, but gets none. In such cases the moist soil is *favorable to the preservation of the raindrops as such,* but we can not say that it *attracts* them from the cloud. This is quite an ordinary case in dry countries. In these cases the moisture is brought from a great distance—a hundred or a thousand miles—by currents of air that are slowly rising and rolling over and over on themselves. The upper part of the roll makes a cloud, the lower part is clear air. Raindrops are formed either slightly at nighttime, when the top of the cloud cools down in the absence of sunshine, or more freely in the daytime, when the vertical extent of the roll is greatly increased by the sun's heat. If in the daytime the overturning extends from sea level upward, then enough moisture is carried up to form a thunderstorm.

I do not see how man can possibly exert any appreciable influence on the formation of rain in your region. The forces involved in this atmospheric overturning, even in the smallest thunderstorm, are enormous. More energy is involved than is represented by all the steam engines in the world. The